Quality of the radiographic image in paper radiography

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QUALITY OF THE RADIOGRAPHIC IMAGE IN PAPER RADIOGRAPHY

J.C. Domanus and H.M. El Fouly

Abstract. The quality of the radiographic image was investigated by the use of standard ISO wire Image Quality Indicators and ASTM Penetrameters. 10, 20, and 30 mm thick welds on alumunium and steel plates were radiographed using X-ray machines with voltages from 35 to 300 kV. Agfa-Gevaert Structurix IC paper with Structurix IC screens Type II as well as Kodak Industrex 600 and 620 and Rapid 700 paper with F1 and F2 screens were used throughout the investigation. The results reached for radiographic paper were compared with those for a fast X-ray film (Kodak Industrex D). The results of the investigation were presented at the International Conference Joining of Metals JOM-1 in Elsinore, Denmark (9-12.8.1981) and at the Second European Conference on Non-Destructive Testing in Vienna (14-16.9.1981). The texts of both papers are reproduced in this report.

INIS-descriptors: COMPARITIVE EVALUATIONS; IMAGES; INDUSTRIAL RADIOGRAPHY; INSPECTION; PAPER; PHOTOGRAPHIC FILMS; QUALITY CONTROL; WELDED JOINTS; X-RAY RADIOGRAPHY.

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RADIOGRAPHIC PAPER FOR THE QUALITY CONTROL OF JOINT STRUCTURES

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Synopsis: The possibility of using radiographic paper instead of X-ray film in the radiographic quality control of metal-joined structures are descussed. Advantages of this technique are presented: lower material, equipment, and labor costs, shorter exposure and processing times, and easier radiation protection. Results of an investigation of radiographic image quality, performed on different brands of radiographic paper and compared with that of fast X-ray film, are given for inspecting aluminium and steel joints. They verify that radiographic paper provides adequate quality for many applications of radiographic control of metal joint structures. Two examples are given of such applications taken from nuclear technology: nuclear fuel and irradiation cans.

I. Introduction

It is common practice to use radiography for the quality control of joint structures. For that purpose X-ray films are commonly used. To get radiographs of a high quality fine grain films are required which need a relatively long exposures due to the slow speed of such films. The processing of X-ray films requires a wet procedure which connected with the necessary drying of the wet films gives a rather long processing time. X-ray machines used for radiography are also rather expensive, especially when fine grain X-ray films are used, which require relatively higher kilovoltages, creating in turn more difficult radiation protection problems. Due to that X-ray film radiography is a rather time consuming and expensive control tool.

There are, however, possibilities to make X-ray radiography cheaper and faster if instead of X-ray film radiographic paper will be used. The use of it presents the following advantages: lower material cost (the paper is 3 to 4 times cheaper than the film),

*) Work performed under contract with Risø National Laboratory.
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shorter exposure and processing times, lighter and less expensive X-ray machines and easier radiation protection problems (as lower kilovoltages for paper radiography are required). The use of radiographic paper for the quality control of joint structures will be possible only then, when paper radiography will assure adequate quality of the radiographic image. This has been investigated on aluminium and steel joints and is reported below.

II. Radiographic paper

For radiographic papers a stabilization processing is used, which can in short be described in the following way. This is a method of producing radiographs on paper much faster than is possible by conventional develop-stop-fix-wash processing. Exposed paper processed by stabilization makes quality, ready-to-use radiographs available in seconds. These stabilized radiographs are not permanent because the chemical reactions within the emulsion have been stopped only temporarily. They will, however, last long enough to serve a number of practical purposes. In fact, stabilized radiographs often remain unchanged for many months if they are not exposed to strong light, high temperature, or excessive humidity.

Stabilization processing is a machine operation in which radiographs on paper are processed in about 10 seconds and leave the processor in a slightly damp condition. They dry completely in a few minutes.

The main differences between stabilization processing and ordinary radiographic processing are in the speed of activation (development) and in the method of treating the unexposed lightsensitive silver halide left in the emulsion after development. In conventional processing, the unused silver halide is dissolved by the fixer and any traces of soluble silver salts left after fixing are removed by subsequent washing. The rsulting radiographs are stable for long periods. In stabilization processing, however, the silver halide is converted to compounds which are only temporarily stable and the radiographs have a limited keeping time. However, stabilized radiographs can be made permanent by fixing and washing after they have served their initial purpose.

In papers designed for stabilization processing, developing agents are incorporated in the paper emulsion. Development is achieved by applying an alkaline activator to the emulsion surface. The stabilizer is then applied to neutralise the activator and to convert any remaining silver halide to relatively stable, colorless compounds.

Figure 1, on the next page, shows a schematic diagram of a paper processor. Further details about the radiographic paper can be found in [1].

III. Intensifying screens

Because of the rather low response of radiographic paper to direct X-rays it must be used with fluorescent intensifying screens with

which it shows a relatively high speed. One can profit by this high speed in two different ways: first, the exposure time can be considerably shortened while keeping the same kilovoltage as for an X-ray film [2] and second, to keep the exposure (mAmin) constant and lower the kilovoltage [3].

The first solution will undoubtedly lower the quality of the radiographic image due to the use of fluorescent intensifying screen, whereas in the second the radiographic contrast of the object to be radiographed will increase (due to the lower kilovoltage in use) and the overall quality of the radiograph will be maintained.

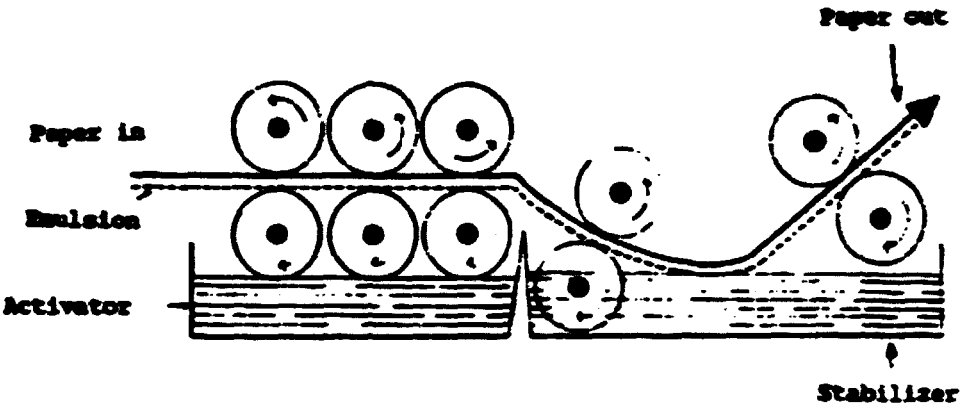

Fig. 1. Schematic diagram of a paper processor.

IV. Radiographic material used for comparison

The following brands of the radiogrphic paper were used: Agfa-Gevaert Structurix IC paper with IC II intensifying screens and Kodak 600, 620 and 700 paper with F1 and F2 intensifying screens. The IC, 600 and 620 paper brands were processed in processors of the type shown on Fig. 1, whereas the 700 paper was hand processed in regular X-ray film processing tanks (development 45 s, fixing 3 min, washing 10 min, drying 10 min).

To compare the quality of the radiographic image on paper with that on X-ray film the Kodak Industrex D (high speed) was used througout the investigation. It was used with 0.05 + 0.10 mm thick lead intensifying screens for kilovoltages exceeding 50 kV. Further details about the comparison between paper and film radiography can be found in [4].

V. Quality of the radiographic image

To verify the usefulness of the radiographic paper the quality of the radiographic image obtained on paper was tested and compared with that of X-ray film. Standard image quality indicators were utilized for that purpose.

ISO wire IQI's were used to assess the quality of radiographs taken at different voltages of 10, 20 and 30 mm thick aluminium and steel plates. The Al plates were radiographed at voltages from 35 to 50 kV, steel plates were radiographed at 125 to 300 kV. In all instances radiographic quality or 2% or better could be reached, which was in many instances worse than that reached with the high speed D film. Throughout the investigation two types of X-ray machines were used: a constant potential 5-50 kV machine with a beryllium window X-ray tube, and above 50 kV two single tank, self-rectified machines (50-180 kV and 100-300 kV).

The results of the image quality investigation can be summarized as follows: For aluminium welds (on plates up to 30 mm thick) best quality can be reached when using the soft X-ray technique (beryllium window X-ray tube). For a 10 mm Al plate a wire IQI percent image quality of 1.25% could be reached for most paper brands when using 35 to 40 kV, whereas the Kodak Industrex D film showed a 1% quality in the same region. For a 20 mm Al plate a 1% sensitivity could be reached for most of the paper-screen combinations at 40 to 45 kV, whereas the D film could give a 0.8% sensitivity. Finally, for a 30 mm Al plate a 0.67% sensitivity can be reached for paper at 45 to 50 kV and a 0.53% sensitivity for the D film.

For steel welds kilovoltages above 125 kV had to be used and consecutively no such good qualities were possible as with the soft X-rays (below 50 kV). Nevertheless, also here paper radiographs of good quality could be produced. A 2% wire IQI quality can be reached with most of the paper-screen combinations at 125 to 175 kV. With the D film at 125 kV a quality of 1.25% is possible. For a 20 mm steel plate a quality of 1.25% can be reached for paper at 150 to 175 kV, whereas the D film is only sligthly better (1.0%). Finally, at 30 mm of steel the paper shows a good quality of 1.33% and the D film 1.07% at kilovoltages between 175 and 225 kV.

Table 1 gives the results of the image quality investigation, where best results reached for different paper brands and the D film are shown.

VI. Applications of paper radiography

From the description of the properties of the radiographic paper given above it appears that one will use radiographic paper in the following instances: if the exposure time has to be shorten considerably, if it is necessary to obtain radiographs ready for assessment in a very short time, if the case of processing and of evaluating the results of radiography is of primary importance, if

Table 1. Best results of radiographic image quality reached with the use of wire ISO IQI's.

Material	mm	% IQI Sensitivity	Paper Brand	Paper Screen	Film Brand	Film Screen	kV
Al	10	1.0 1.0	620	F2	D	O	35 35,40
	20	0.8 0.9 0.8	IC 620	IC II F1	D	O	40,45 40 50
	30	0.67 0.67 0.53	IC 620	IC II F1	D	O	45,50 45 50
Fe	10	1.6 1.25	600	F1	D	Pb	125 125
	20	1.0 1.0	700	F2	D	Pb	150 150,175,200
	30	1.33 1.33 1.33 1.33 1.33 1.07	IC 600 620 620 700	IC II F1 F1 F2 F1	D	Pb	175,250 175,200,250 225 175,200,225 175,200 200,225

radiation protection presents difficulties which can be alleviated by use of lower doses and lower kilovoltages and finally if objects of low attenuation (low atomic number of small tickness) are to be examined.

One of such instances, where one will profit by all those advantages of the radiographic paper, is the gas industry. The use of the radiographic paper for the radiographic control of pipeline welds in the gas distribution net, in the conduits ascending to the habitations and on transport pipelines at Gaz de France is described in [5], where further references on that subject can be found. Paper radiography is used for several years at Gaz de France for controlling steel welds on steel pipes with wall thickness up to 15 mm.

Other examples can be given e.g. for the nuclear technology. At Risø National Laboratory during the production of fuel plates for the MTR reactor paper radiography is extensively used at different stages of the production. One of those consists of welding 1.5 mm thick aluminium plates, where e.g. microporosities can be revealed on paper radiographs (see Fig. 2). Paper radiography is also used in testing the quality of welds on products using new technology, e.g. on titanium welded irradiation cans.

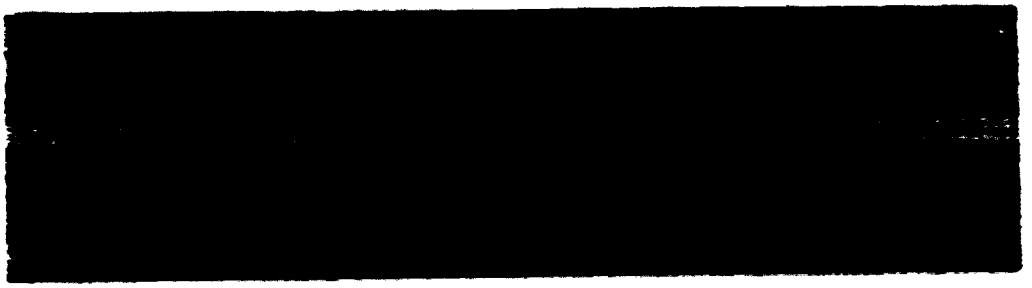

Fig. 2. Paper radiograph of a 1.5 mm Al weld, taken at 25 kV.

VII. Conclusions

In different international [6] and national [7, 8, 9] standards requirements are given regarding the radiographic quality levels. They are different for different radiographic techniques. According to the ISO/R.947 and ISO/R.1106 for X-ray radiography two classes of X-ray technique are available: Class A - general technique, and class B - more sensitive technique. This corresponds to the two classes given in DIN 54111 [9]. The requirement for class B given in ISO 2504 [6] requires a 2% wire IQI quality for a 10 mm weld, a 1.25% for 20 mm and a 1.07% for 30 mm. According to the DIN [9] standard the requirements for class A and B are the following: for 10 mm - 3.2 and 2.0%; for 20 mm - 2.0 and 1.25% and for 30 mm - 1.67 and 1.07%. The general requirement of the ANSI/ASTM [7, 8] is that "the quality level for radiography shall be at least 2%".

If one will compare the above mentioned requirements with the results reached in the present investigation and summarized in Table 1, one will come to the conclusion that the radiographic paper can meet the requirements set out both in the ISO as well as the DIN standards for class B (more sensitive technique) for aluminium welds up to 30 mm thick and for steel welds up to 20 mm. If, however, only the class A (general technique) is required then even at 30 mm of steel the radiographic paper can meet the above requirements. As to the ANSI/ASTM general requirement about at least 2% quality level, it has also been proved (by the use of the ASTM penetrameters) that this requirement can be met by the radiographic paper both for Al and Fe up to 30 mm.

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[8] ANSI/ASTM E142-77. Standard method for controlling quality of radiographic testing.

[9] DIN 54 111. Zerstörungsfreie Prüfverfahren. Prüfung von Schweissverbindungen metallischer Werkstoffe mit Röntgen - oder Gammastrahlen. Aufnahme von Durchstrahlungsbildern.

SECOND EUROPEAN CONFERENCE ON
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VIENNA
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ISO DRAHTSTEGE GEGEN ASTM PENETRAMETER IN DER PAPIERRADIOGRAPHIE

ISO WIRE IQI'S VS. ASTM PENETRAMETERS IN PAPER RADIOGRAPHY

ISO INDICATEURS D'IMAGE A FILS CONTRE ASTM PENETRAMETRES DANS LA RADIOGRAPHIE SUR PAPIER

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Beim Vergleich der verschiedenen Eigenschaften des radiographischen Papiers mit hochempfindlichen Röntgenfilm wurde die Bildgüte von Al und Fe Schweissnähten (10, 20 und 30 mm dick) mit Hilfe der ISO Drahtstege und ASTM Penetrameter untersucht. Die Bildgüte erreicht mit beide Methoden wurde verglichen.

While comparing different properties of radiographic paper with high speed X-ray film, image quality of Al and Fe welds (10, 20 and 30 mm thick) was controlled by the use of ISO wire image quality indicators and ASTM penetrameters. Radiographic sensitivities reached by both methods were compared.

Dans la comparaison des différénts qualités du papier radiographique avec celles du film, la qualité d´image des soudures sur plaques en Al et Fe (10, 20 et 30 mm épais) etait comparé a l´aide des indicateurs d´image à fils ISO et penetrametres ASTM. Les qualités d´image obtenus par les deux methodes furent comparées.

1. INTRODUCTION

The properties of the radiographic paper and its applications in industrial radiography have been extensively investigated at Risø before, and the results were published in [1, 2, 3]. In those investigations the quality of the radiographic image on radiographic film and paper was compared by the use of wire IQI's (for Al and Fe plates) [1, 2, 3], by Al step wedges (for U/Al nuclear fuel plates) [1, 2, 3] by special made hole indicators (for U/Al blocks, from which fuel plates are thereafter rolled down) [1, 2, 3] and by stepped specimens (for reinforced composites) [1, 2, 3, 4]. Also artificial and natural defects were used for that purpose [3]. While evaluating radiographic paper quality for applications in the US Air Force, MIL-Standard 453 penetrameters were used by Holloway and Bohlen [5]. The MIL penetrameters are the same as described in the ANSI/ASTM E 142-77 standard [6].

As a direct comparison of radiographic image quality for the radiographic paper tested by the ISO wire IQI's [7] and the penetrameters could not be found in the current literature it was decided to perform such a comparison using 10, 20 and 30 mm welds on aluminium and steel plates. Results of this comparison are described below.

*) Work performed under contract with Risø National Laboratory.
**) Fellowship holder at Risø National Laboratory under the United Nations International Atomic Technical Assistance Program.

2. EXPERIMENTAL SET-UP

The radiographic quality was investigated using welds on aluminium and steel plates (10, 20 and 30 mm thick). On each plate a suitable wire IQI's and penetrameters were placed. The radiographs were then assessed by three observers and only smallest wires and holes seen by all the three observers were taken into consideration.

The plates were radiographed using a constant potential 50 kV (with beryllium window X-ray tube) and a 180 selfrectified, unit-tank X-ray machines. For the first voltages from 35 to 50 kV were used whereas the later was operated between 50 and 130 kV. Similar steel plates were radiographed by a 300 kV selfrectified, unit-tank machine at voltages from 125 to 300 kV.

Following brands of radiographic paper and fluorescent intensifying screens were used: Kodak Industrex 600 and 620 as well as Rapid 70C paper (all with F1 and F2 screens) and Agfa-Gevaert Structurix IC paper with IC type II screen. For comparison with X-ray film the Kodak Industrex D film was used. For kilovoltages up to 50 kV (the 50 kV machine) it was used without intensifying screens whereas for voltages above 50 kV (the 180 and 300 kV machines) lead 0.05 + 0.10 mm screens were used. The 50 kV machine had a 0.5 mm focus whereas the 180 and 300 kV machines had 2.3 and 4.0 mm foci. All exposures were made at 1 m FFD.

3. IMAGE QUALITY INDICATORS AND PENETRAMETERS

The relative merits and disadvantages of use of the ISO wire IQI's and the ASTM penetrameters can be summarized as follows: The wire IQI's are more universal in use, as for practically all thicknesses of the examined object the same set of three IQI's can be used. If e.g. the DIN 54 109 IQI's are used, containing 16 different wires, grouped into three sets (1/7, 6/12, 10/16), then the range of wire diameters streches from 0.1 to 3.2 mm. This means that e.g. for objects with thicknesses from 10 to 320 mm a 1% radiographic sensitivity can be checked. On the contrary, with the ASTM penetrameters for each thickness of the object under control a separate set of three penetrameters is required in principle (as their thicknesses shall be 1, 2 and 4% of the object thickness). The ASTM penetrameters present an advantage when the penetrameter sensitivity is calculated. Here for each penetrameter constant values of sensitivity are set by its constant percent thickness and constant relation of its hole diameters to this thickness. On the contrary the ISO wire IQI's will give different IQI sensitivities for the same visible wire, depending on the thickness of the examined object. The differences between the ISO ans ASTM systems can be best illustrated by the following example taken for 10, 20 and 30 mm thick plates, as used throughout this investigation.

4. RADIOGRAPHIC IMAGE QUALITY

As mentioned before a direct comparison was made of radiographic image quality obtained by the use of the ISO wire IQI's and the ASTM penetrameters for various brands of radiographic paper and a high speed X-ray film. The results thereof are presented in the following six diagrams.

Percent IQI sensitivity (by the ISO method).

Plate thick-ness t mm	Minimum visible DIN wire diameter on a plate of t mm															
	Wire No.															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Wire diameter - mm															
	3.20	2.50	2.00	1.60	1.25	1.00	0.80	0.63	0.50	0.40	0.32	0.25	0.20	0.16	0.125	0.100
10	32	25	20	16	12.5	10.0	8.0	6.3	5.0	4.0	3.2	2.5	2.0	1.60	1.25	1.00
20	16	12.5	10	8	6.25	5	4	3.15	2.5	2.0	1.6	1.25	1.0	0.8	0.63	0.50
30	10.67	8.33	6.67	5.33	4.17	3.33	2.67	2.10	1.67	1.33	1.07	0.83	0.67	0.53	0.42	0.33

Percent penetrameter sensitivity
(by the ASTM method)

Penetrameter thickness %	Minimum perceptible hole diameter %	Equivalent penetrameter sensitivity %	Level of inspection
1	1	0.7	1 - 1T
	2	1.0	1 - 2T
	4	1.4	1 - 4T
2	1	1.4	2 - 1T
	2	2.0	2 - 2T
	4	2.8	2 - 4T
4	1	2.8	4 - 1T
	2	4.0	4 - 2T
	4	5.5	4 - 4T

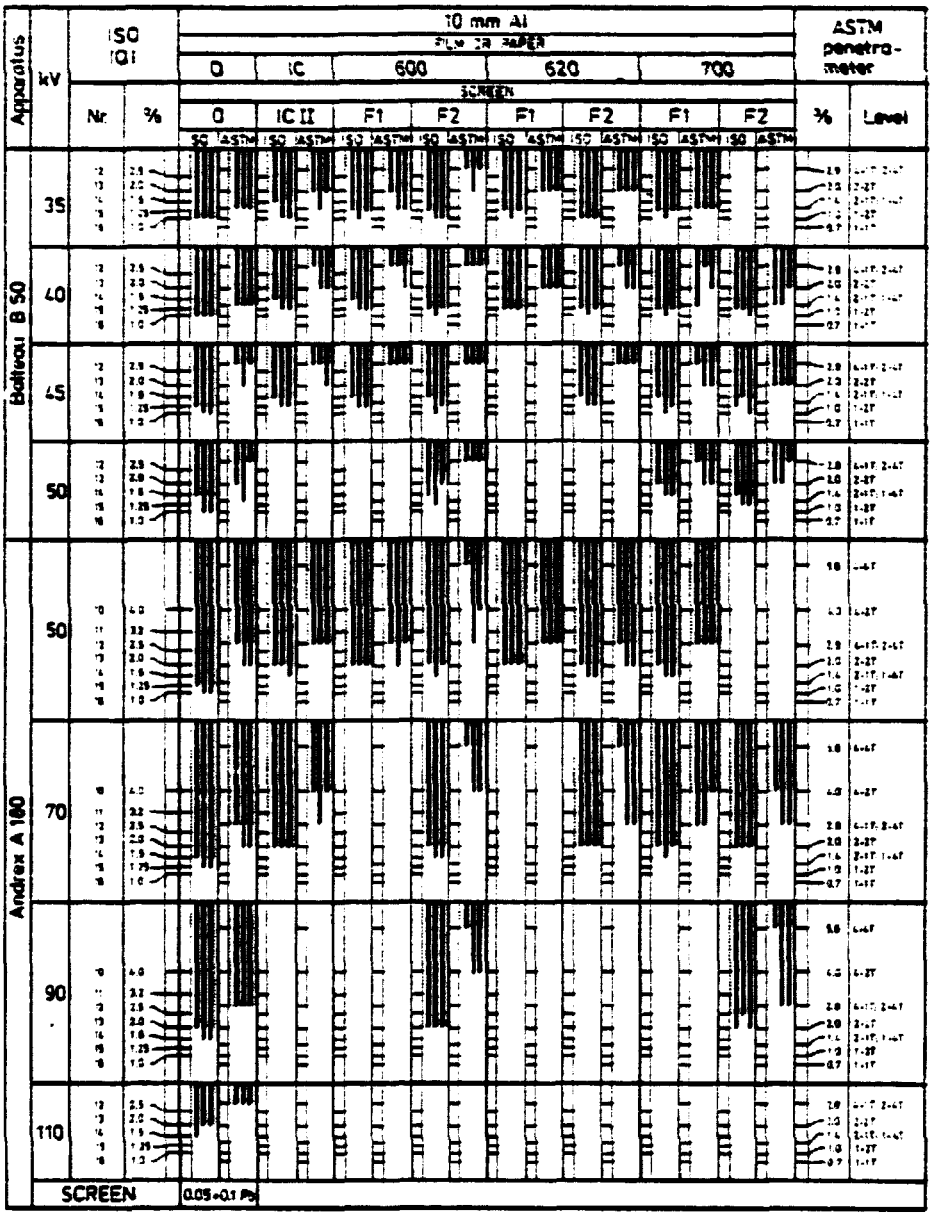

Fig. 1. Image quality for 10 mm Al.

4.1. Aluminium

For the thinnest Al plate (10 mm) wire IQI sensitivities are always better for the high speed film than for paper. Only one paper/screen combination (620/F2) could once (at 35 kV) give the same results (1%) as the film. The film is also less sensitive to the voltage increase than paper. The 1% sensitivity reached with the wire IQI could never be reached with the ASTM penetrameter, which showed the best level of 2-1T (1.4%) both for D film and the 700/F1 paper combination. Nevertheless, the 2% sensitivity can easily be reached for film or paper both for the wire IQI as well as the ASTM penetrameters if correct (low) kilovoltage is chosen.

For the 20 mm plate equally good results could be obtained for the D film and IC/IC II paper combination for wire IQI's (but at slightly different voltages: 50 and 45 kV respectively). Also here the present ASTM sensitivity was worse than that reached with ISO wires, although the 2-1T level (1.4%) could be reached for several paper/screen

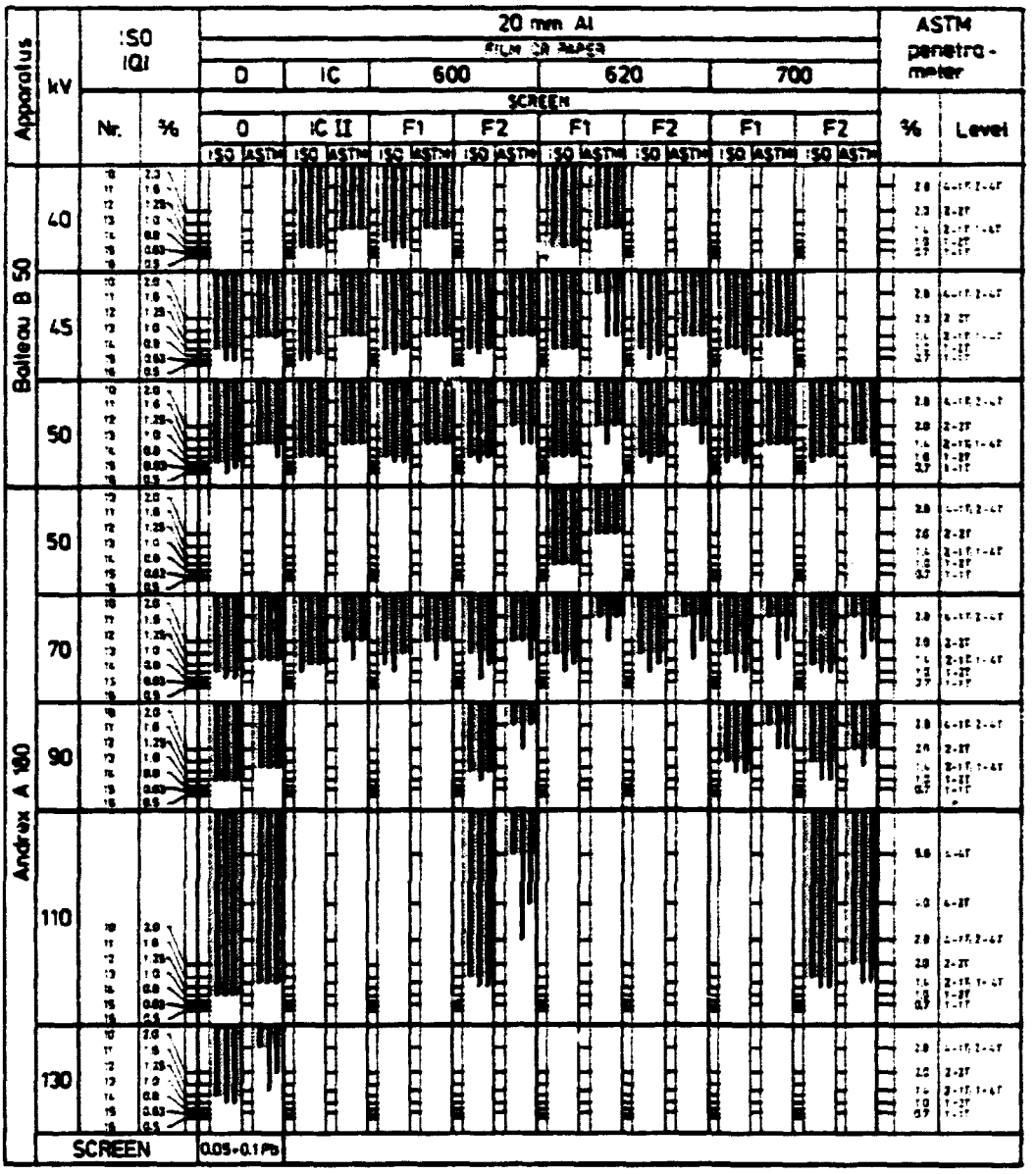

Fig. 2. Image quality for 20 mm Al.

combinations.

At 30 mm the D film was by one wire better than any paper/screen combination at any kilovoltage. Also here the 2-1T level (1.4%) could be reached for several paper/screen combinations.

In general the 2-2T level (2%) can easily be reached for all Al plates and paper/screen combinations. This is also true for the 2% wire sensitivity.

The ASTM penetrameter sensitivity was also investigated for a larger range of Al thicknesses (3.18 to 88.90 mm) with a constant potential X-ray machine (45 to 160 kV) by Holloway and is summarily reported in [7], whereas [8] gives full details.

4.2. Steel

For the investigation of steel a selfrectified X-ray machine was used.

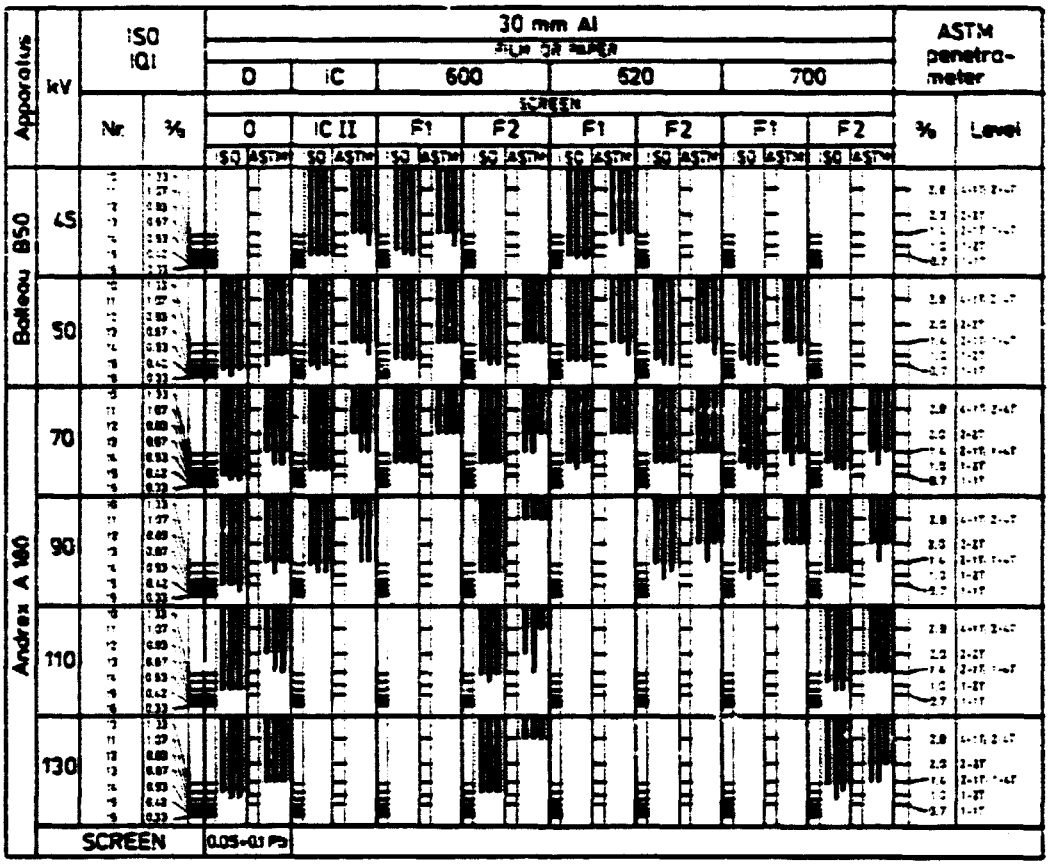

Fig. 3. Image quality for 30 mm Al.

At 10 mm only the D film could give the 1.25% wire sensitivity, whereas the 2-2T penetrameter level (2%) could be reached with several paper/screen combinations at different kilovoltage. It could, however, not be reached on the D film.

At 20 mm the 0.8% wire sensitivity could be reached at 150 kV both for the D film as well as the 700/F2 paper. The same was true for the 2-1T level (1.4%), whereas the 2-2T level (2%) could be reached by almost all paper/screen combinations.

At 30 mm the D film shows the best wire sensitivity (1.07%), whereas equal penetrameter 2-1T level (1.4%) can be reached both for the film and paper.

Unfortunately, no such comparative investigation of radiographic quality for paper and steel could be found in the literature.

5. CONCLUSIONS

While comparing the results of radiographic image quality investigations performed with the ISO wire IQI's and ASTM penetrameters the following conclusions can be drawn:

1) The ASTM penetrameter level 1-1T (0.7%) could never be reached, neither with the film nor with the paper.
2) The 1-2T level (1.0%) could be only exceptionally reached and only for the D film (30 mm Al at 50 kV).
3) In most instances reaching the 2-1T level (1.4%) is possible both for film and paper.

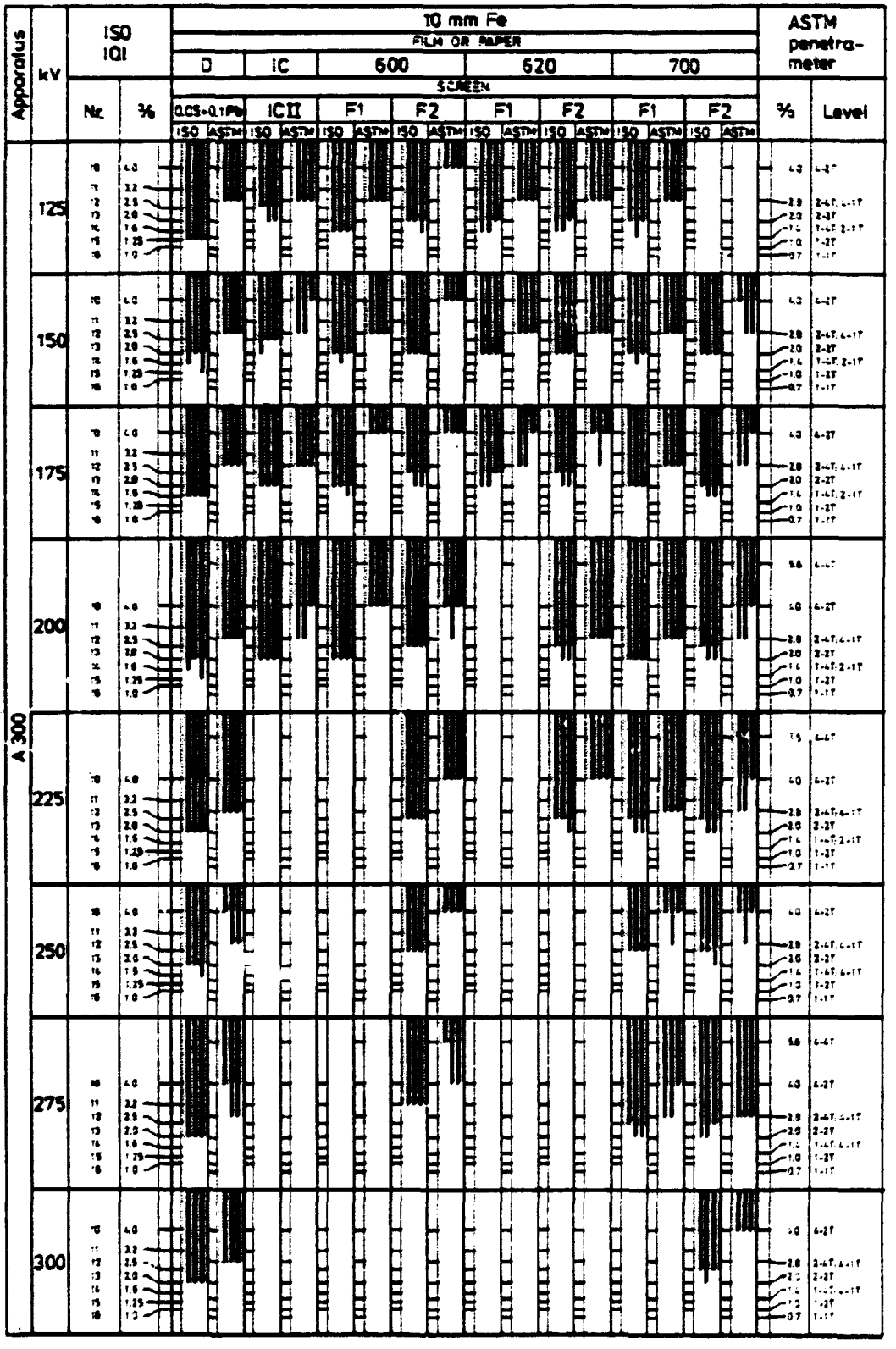

Fig. 4. Image quality for 10 mm Fe.

4) For the same film or paper brand the absolute wire percent sensitivity was always better than that for the penetrameter.

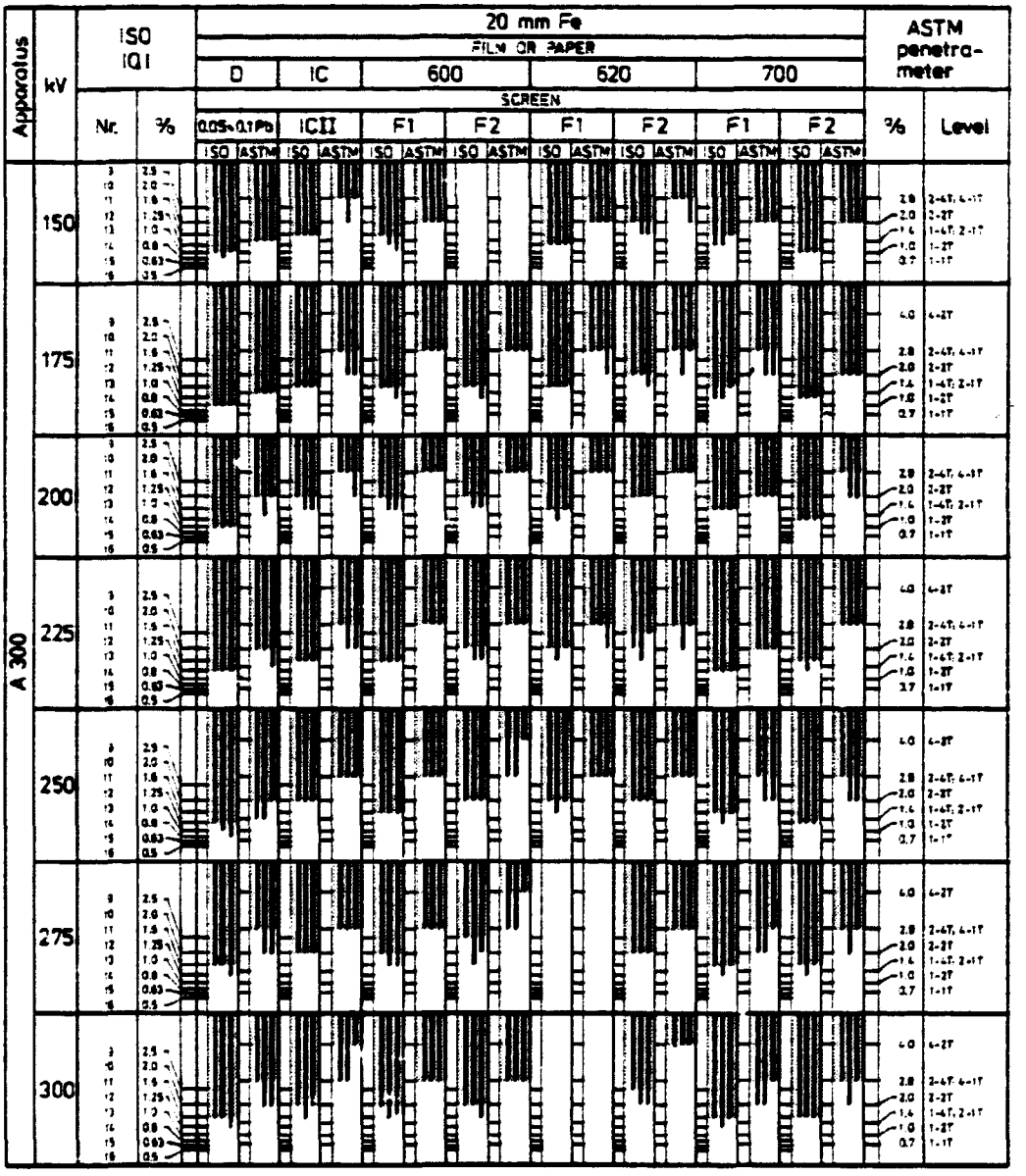

Fig. 5. Image quality for 20 mm Fe.

5) This means that it is easier to detect a wire of the same diameter as a hole in a penetrameter. This difference is more visible for the paper than film.
6) From the above investigation no definitive conclusion can be drawn about the superiority of any brand of the radiographic paper.
7) The same is true when one compares the use of the Kodak F1 and F2 screens with different brands of the Kodak paper.
8) As a general conclusion it can be said that it is easier to assess the radiographic image quality of the radiographic paper with the ISO wire IQI's than the ASTM penetrameters.

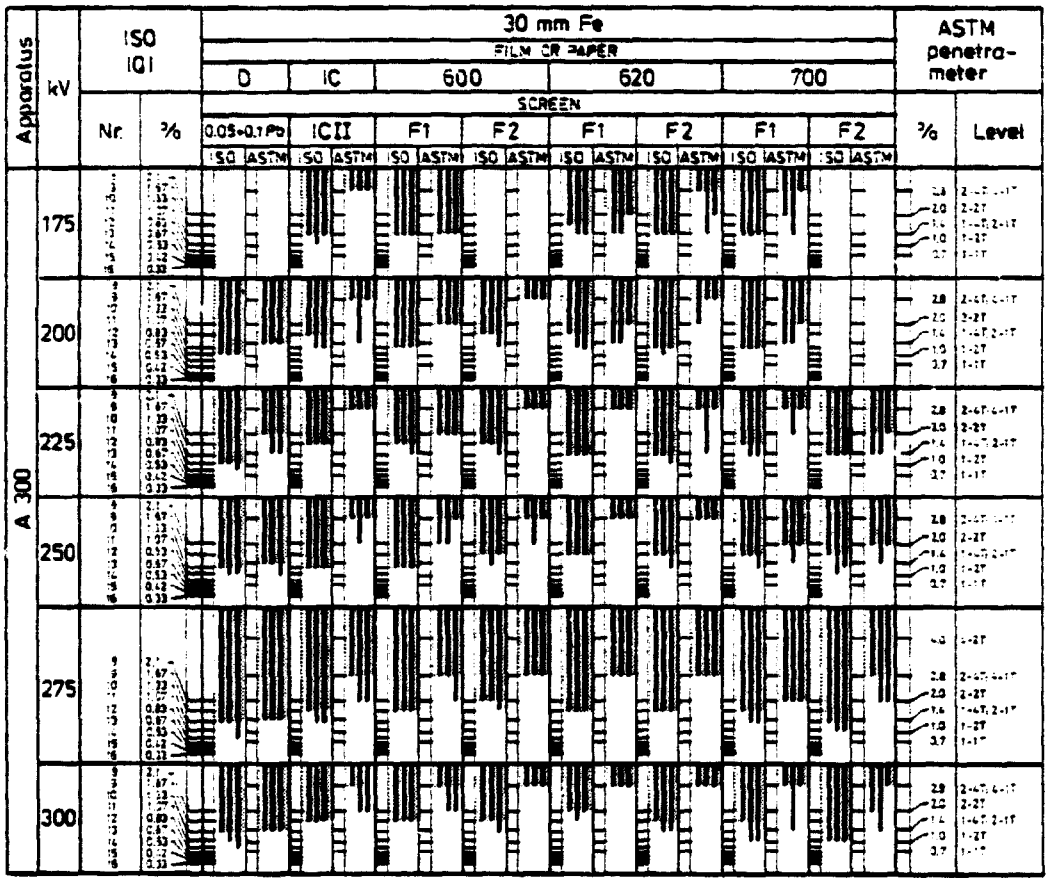

Fig. 6. Image quality for 30 mm Fe.

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Quality of the radiographic image in paper radiography

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Abstract

The quality of the radiographic image was investigated by the use of standard ISO wire Image Quality Indicators and ASTM Penetrameters. 10, 20, and 30 mm thick welds on aluminium and steel plates were radiographed using X-ray machines with voltages from 35 to 300 kV. Agfa-Gevaert Structurix IC paper with Structurix IC screens Type II as well as Kodak Industrex 600 and 620 and Rapid 700 paper with F1 and F2 screens were used throughout the investigation. The results reached for radiographic paper were compared with those for a fast X-ray film (Kodak Industrex D). The results of the investigation were presented at the International Conference Joining of Metals JOM-1 in Elsinore, Denmark (9-12.8.1981) and at the Second European Conference on Non-Destructive Testing in Vienna (14-16.9.1981). The texts of both papers are reproduced in this report.

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